



M55 Rocket Fire/ Explosion Concerns

ABSTRACT

CDC convened a group of Subject Matter Experts (SMEs) consisting of 4 members with the following experience: chemical and petrochemical process hazards and investigations, propellant and explosives manufacturing and testing, risk evaluation and incident investigation, mechanical processing and environmental issues to review the Army's investigation into recent fires involving the destruction of M55 chemical agent rockets. This group reviewed the Army's investigation approach including reviews such as the propellant analysis, structural evaluations of the containment area, risk evaluations and the contractor's modifications to equipment. Key findings of this review include:

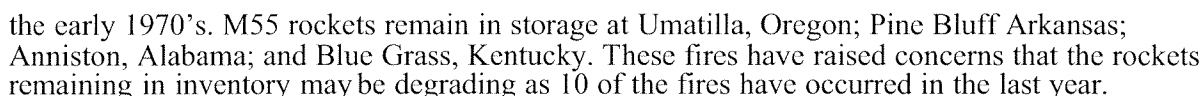
- (1) While there seem to be unknowns surrounding the destruction of rockets (e.g. leaking or sensitive rockets) there are no immediate concerns for worker and public health that would preclude the continued processing of rockets.
- (2) The Explosion Containment Rooms where the fires are occurring have a sufficiently robust design such that there should be no increased risk to workers and the public.
- (3) The modifications made by the systems contractor appear sufficient to potentially minimize the frequency of fires, and contain or suppress the fires.
- (4) The actual root causes of the fires have never been completely substantiated.
 - a. Testing and analysis of rocket samples has not been sufficient to completely identify the specific root cause(s) of the fire events.
 - b. Issues regarding the storage and handling of rockets need to be investigated further. These issues include items such as leaking rockets and inadvertent arming of fuzes
 - c. Updates of the risk analyses were approached from the standpoint that the rocket fires are random events, which has yet to be fully confirmed.

The SMEs focused on how the studies and conclusions impact the entire chemical agent stockpile elimination activities including the Assembled Chemical Weapons Alternatives efforts, which include the design of a non incineration process to dispose of M55 rockets. The SME's recommendations focused on further understanding of the root cause of the rocket fires, its impact on health and safety and possible implications for the Blue Grass design of a new facility to eliminate the stockpile at that site. The proposed Blue Grass facility will incorporate chemical destruction of the chemical agent and energetics and will incorporate a new rocket processing method. It was felt that if the existing sites, which use incineration, can continue to eliminate the stockpile of rockets within the next 1-1/2 to 2 years, many of the issues raised by the SMEs for storage should be minimized for those sites. However, for the proposed Blue Grass facility, it is important to understand these issues and how they could impact the design or to verify they are not an issue.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2006		2. REPORT TYPE		3. DATES COVERED 00-00-2006 to 00-00-2006	
4. TITLE AND SUBTITLE M55 Rocket Fire/Explosion Concerns				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Chemical Materials Agency, 5183 Blackhawk Road, Aberdeen Proving Ground, MD, 21010-5424				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 20	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



Since 1994, incinerators built to destroy chemical weapons have had 21 fires involving the processing of M55 rockets. M55 rockets are small field units designed and built in the early 1960's with chemical agents including sarin and VX in the warhead. While never used in combat, these rockets have been stored awaiting destruction since



Storage of the rockets should have been at relatively constant temperatures near ambient due to the insulating effects of the storage igloos for much of the past 30 to 40 years. Time, temperature and humidity are key components to the degradation of the solid propellant and other energetic materials contained in the rocket. This degradation can potentially lead to increased sensitivity of the components to static, shock and thermal effects as well as the possibility of ignition. With the recent increase in rocket fire events occurring during rocket chopping prior to incineration, there was concern there was an immediate risk of such events interrupting and possibly damaging rocket destruction processes. The CDC and the Army were concerned the risk might extend to those activities involving rockets prior to the rocket chopping process. Such activities include storage and inspection of existing inventory, movement of rockets to the destruction facility, and manual handling of rockets to feed the destruction process. A detonation or ignition at any of these points could result in possible involvement of other rockets, injury or death to site personnel. In addition, CDC felt it was important to assess if there were any risks to neighboring communities.

- Prior to November 2004 there were 4 rocket fires out of 150,000 rockets destroyed. Since that time through December 2005 there have been 17 rocket fires out of the additional 90,000 plus rockets destroyed with at least 9 of these due to propellant anomalies.
- All of the rocket fires have been with GB (sarin) warhead rockets; however, the majority of the VX rocket stockpile has yet to be processed.
- There have been 4 pressure pulse events (possible explosions) associated with the Umatilla operation and one of these resulted in the splitting open of the casing. These events suggest that there is an ignition mechanism associated with the initial blade contact on the steel propellant section. In the other events there was normally a 3-11 second lag after the 5th cut (in the chopping operation) before the fire ensues.



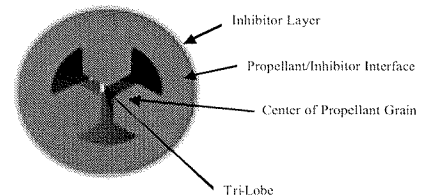
KEY ARMY ACTIVITIES

1. US Army Response to the Rocket Fire Risk

The US Army characterized propellant of the rocket lots with the assistance of experts in the US Army's Picatinny Arsenal Laboratory in New Jersey. The original specifications of the propellant are given in Table 1.

Table 1. Nominal Composition of Double-Base Propellant

<u>Constituent</u>	<u>Weight Percent</u>
Nitrocellulose (NC)	60.0
Nitroglycerin (NG)	23.8
Triacetin (TA)	9.9
Dimethylphthalate (DMP)	2.6
Lead Stearate	2.0
<u>2-Nitrodiphenylamine (2-NDPA)</u>	<u>1.7</u>
Total	100.0



Visual inspections were performed on the rocket motor assemblies once they were received at Picatinny Arsenal's Laboratory. The external surface of the propellant was evaluated for the presence of nitroglycerin (NG). The migration of the NG to the external surface has the potential to create sensitive areas that would be susceptible to impact. Results of the tests confirmed the presence of NG on the surface in association with TA and DMP. Picatinny Laboratory tests showed that both the propellant and NG-saturated inhibitor layer are relatively insensitive to friction, impact, and electrostatic (human) discharge (ESD).

It was hypothesized (but not demonstrated) that "sensitive" concentrations of NG might accumulate as "sweat" (droplets) or "exudates" (pools) on the outside surface of the propellant grain. The proposed ignition of NG sweat or exudate, postulated by the Army, should be a stochastic event (e.g., a random NG rich droplet on the surface of the propellant struck by the rocket chopping blade). Flushing the blade with water should minimize the likelihood of such an event (which was implemented into the operations at Pine Bluff and Umatilla Army Depots).

2. Site Contractor Response to the Rocket Fire Risk

The Army's Contractor, Washington Demil Corporation (WDC), operates the chemical weapon disposal operations at Anniston (AL), Umatilla (OR) and Pine Bluff (AR). WDC developed plans to continue operation and minimize the frequency and impact of fires and ensure there is no harm to the personnel or unacceptable risk to personnel, public and the environment. Their modifications included an enhanced shear spray delivery, enhanced water deluge sprays (to control flame spread and cooling), and other modifications to detect pressure rises due to fire or explosion and activation of the fire suppression systems. In addition, backup contingencies for major future modifications requiring significant downtime were proposed, but not implemented. Since storage and movement to the operations is conducted by the Army, the contractor did not review these issues.



3. Other Army Groups

The US Army's Assembled Chemical Weapons Alternatives (ACWA) group is currently designing a new facility to destroy all the weapons stored at the Blue Grass Chemical Depot in Kentucky (BGCD), but this will not be online for 6 to 7 years. This facility will not use incineration, as at the other sites listed, but will incorporate a new technology that involves chemical destruction of the chemical agent, rocket motors and energetics. ACWA has a proposed plan from their contractors, Bechtel and Parsons, providing a new design to decouple the rocket motors from the warheads for the 70,000 plus M55 rockets stored in the Kentucky facility. The plan calls for a separation of the rocket motor section from the warhead by a method to be determined. The warhead would be further cut/ chopped and processed, along with contaminated rocket motor sections in a machine similar in design to those in the three WDC facilities. However, while the unit is expected to be similar, it will not be identical and any changes in the rocket chemistry need to be determined to ensure a safe design. It must be emphasized that these plans are still in the design phase and have not been finalized as of this report.

CDC'S CONCERNS

CDC had programmatic concerns with the root cause and impact of the rocket fires and accordingly convened a group of Subject Matter Experts (SMEs) consisting of 4 members with the following experience: chemical and petrochemical process hazards and investigations, propellant and explosives manufacturing and testing, risk evaluation and incident investigation, mechanical processing and environmental issues. Resumes of each of these experts are attached to this report. This group reviewed the Army's investigation approach including reviews such as the propellant analysis, structural evaluations of the ECR processing area, risk evaluations and the contractor's modifications to equipment. The SMEs focused on how the studies and conclusions could more broadly impact the entire chemical agent stockpile elimination effort including the ACWA program. Hereafter, any reference to "SMEs" will be to the CDC SMEs.



Pallets of Rockets in Normal Storage Configuration Being Transferred



THE FINDINGS OF THE ARMY INVESTIGATION

The working group completed their investigation and concluded there was no danger to workers or surrounding communities from the fires contained within a structure known as an Explosive Containment Room (ECR). All of the ECRs were designed and engineered to contain explosions of up to 2 M55 rockets and have accommodated the fire events to date. However, this conclusion was based strictly on the capabilities of the ECR and does not include potential risks from storage and handling.

The Army published its findings in three reports on various aspects of the investigation. The reports were prepared by the U.S. Army Armament Research, Development and Engineering Center/Army Research Laboratory in Picatinny, New Jersey; Washington Group International (WGI), the operations contractor at the three CMA sites involved with the recent fires; and Mitretek Systems, a non-profit public interest corporation that provides independent research and analysis for federal, state and local governments. The CDC's SMEs conducted a review of these efforts and the reports; and their assessments are given below. Their findings were based on a series of basic questions the CDC asked them to consider based on their expertise and the information they reviewed.

SME ASSESSMENT OF THE ARMY REPORTS

The Army undertook a parallel approach to addressing the problem of rocket fires which was very reasonable. One pathway involved the identification of the root cause(s) of the rocket fires by testing rockets from Umatilla and Pine Bluff, and the other pathway involved the investigation of various rocket processing options, both short term and long term, to prevent and mitigate future rocket fires. The approach was well designed and was carried out reasonably well. The final reports documented and summarized the Army's conclusions and plans forward.

The test work at Picatinny on the Umatilla and especially the Pine Bluff rockets produced valuable insights into possible fire mechanisms. The striking of NG exudates on the surface of the propellant grain during shearing was cited as the most probable cause of the fires. However, this cause is based on a mass transport process involving the migration of NG into the inhibitor layer, where a humidity dependent equilibrium state is thought to be achieved in just a few years. The incidence of fires should therefore be a stochastic process based on simple probability and fire events should have been occurring randomly over time. However, the recent rash of fires suggest that there may be time dependent degradation and sensitization processes that may be taking place that have not been completely identified. The fact that there may be some uncertainty regarding the rocket fire mechanism raises additional questions on longer term rocket stability and sensitivity in other areas of the process including storage, movement, handling and transportation. In spite of the extensive testing and analytical work the SMEs do not believe that sufficient testing has been carried out to confirm the Army's fire initiation mechanism and believe there are still a number of unanswered questions around that topic that should be addressed. An additional cause hypothesized at the outset of the review by the SMEs is the possible initiation of a fire event via a thermite reaction. The steel blade will pick up bits of aluminum following cut #4 which could result in a reaction with rust on the inside surface of the rocket casing or just result in blunting of the blade. The water spray improvements might help in



removal of aluminum debris but will more likely help in the quenching of any thermite reaction that might be initiated.

Storage Issues

The SMEs felt the Army did not address a number of issues regarding the storage of rockets, particularly at Blue Grass, where storage is expected to continue for at least another 5 to 6 years. If the existing sites can continue to eliminate the stockpile of rockets within the next 1-1/2 to 2 years, these issues should be minimized at those sites. For the Blue Grass site, it is important to understand these issues, how they could impact the design or to ensure they are not an issue. Of particular concern is the storage environment which might produce potentially higher temperatures and higher humidity in the summertime. Photographic evidence of the rocket samples from Pine Bluff indicated the presence of an orange powder which is thought to be rust. It would follow that Blue Grass should have a similar environment for humidity as compared to Pine Bluff and may have even higher humidity. Higher humidity can also exacerbate potential reactions including the formation of hydrofluoric acid from the degradation of GB in leaking rockets that could possibly leak towards the trilobe area or into the fuze area. Conversely, low humidity can enhance NG migration from the grain to the inhibitor layer.

If a degradation/sensitization process occurs within the rockets over time, then long term storage of the rockets may present some risk. Anniston, Pine Bluff and Umatilla, barring any major issues, anticipate processing all of their rockets within the next 2 years. This issue is of primary interest for the Blue Grass site. It is important to establish there are no time dependent degradation/sensitization processes occurring; therefore, the SMEs are recommending additional testing to address this. Additional testing of the rockets will have specific safety concerns associated with items such as the transport, handling, and performance of the tests. Therefore, it is the opinion of the SME's that specific testing and test protocols would best be left to the Army to develop.

The SMEs expressed concerns around the leaking GB rockets which are currently held in overpack containers and which will not be processed until the end of each site's rocket campaigns. Autoignition for normal rockets based on internal reactions within the propellant grain, coupled with the heat removal process, is thought to be a very low risk by the Army. While a thorough statistical analysis for normal rockets was conducted, frequency calculations for outliers (e.g. GB leakers) were not conducted or assessed. However, based on a risk analysis of leaking GB rockets conducted by SAIC in 2002, some of the SMEs concluded the risks in Umatilla due to leaker autoignition were comparable to those for natural events such as lightning and earthquakes.

Conversely, some of the SMEs also believe the GB leakers have an increased potential for autoignition beyond the cases examined and calculated by SAIC. The assumptions made regarding the internal heat generation rate and heat removal capability, coupled with the lack of detail provided to the SMEs about how the heat balance is actually calculated, have resulted in some uncertainty and therefore, their concern. There was also some concern regarding sensitivity of the leaking rockets even if they are stored or handled perfectly horizontal. During handling



there could be scattering of pyrotechnic from a failed cup (is discussed in a later section). This could occur if the rockets are tipped or on rough surfaces. It is recommended that sampling and analysis of any rockets that have been handled in this manner or not stored perfectly horizontal be conducted to address this concern.

After reviewing the previous Quantitative Risk Analysis performed for rocket processing, there were some questions expressed by the SMEs regarding the stacking height of the rocket pallets and protection of the igloos from lightning hazards. This concern is for all the M55 rockets, but especially those stored at Blue Grass. The stockpiles at Umatilla, Anniston and Pine Bluff are continuing to be reduced and this hazard will become less of a concern at those locations.

Safe standoff distances were calculated by the Army for Blue Grass and recommendations made to employ those standoff distances, and to consider additional protection to reduce the lightning risk. The SMEs were unable to determine whether what, if any, measures were undertaken and, the current status. For those that may have been implemented, the Army's policies require an annual review to ensure they are being followed and maintained. Therefore, the SMEs recommend the Army review the status of the recommendation for lightning protection to ensure appropriate measures were implemented, that they are continuing to be followed and are subject to annual reviews per Army policy.

The risk of an earthquake at the Blue Grass site is as great or greater than the risk at other sites because of the proximity of the New Madrid fault and the rockets will continue to be stored there for some time in the future. Previous safety reviews recommended that the stack heights at Blue Grass be reduced to 4 pallets, or that they be banded together, or that some other means be employed to reduce the risk of falling in the event of an earthquake. It is recommended the Army verify that an appropriate mitigation was implemented and, as stated previously, that it is being reviewed annually and maintained.

The continued destruction of rockets will reduce the overall storage risks from autoignition and natural events to the workers and public. Early destruction of leaking rockets will potentially reduce that risk to a greater degree. It is therefore recommended processing of rockets should continue as rapidly as can be accomplished safely and, as practical, consideration should be given to move leaking rockets to the top of the processing list.

Movement, Handling, and Transportation

One issue identified by all the SMEs is the potential for inadvertent arming of rockets. Two incidents of fuze initiation have occurred at Umatilla in 2005. To the SMEs knowledge no significant investigation took place and no causes were identified. This item was not addressed in the Army report. The SMEs were puzzled by the apparent lack of a root cause investigation on these events. In addition, they did not have any information on the design of the fuzes. As a result, they postulated some possible mechanisms how the arming of a rocket might take place. These include general handling, severe corrosion of the metal spring from leakage of agent, and prior improper assembly. The handling issue is one which should be addressed by the Army's annual review of the current SOPs, and ensuring the retraining/ updated training of individuals involved in handling, including the unpack area. In addition the Army uses rubber mats in the



unpack area to absorb the energy of a falling rocket. However, one concern that should be addressed is how rockets are transported and whether there are other safer means to accomplish that task. The movement, transportation and handling of the rockets should be re-validated and reviewed to ensure the safeguards and procedures are being maintained and also updated based on any new data or information.

Operator and Contractor Approach and Issues

A major problem in the fire investigations was that there was no true root cause analysis conducted which pinpointed the specific causes. In most instances the investigation focused on the location and timing of the fire and the ability of the mitigative systems to respond. What was discovered was that each site implemented different mitigations such as slightly different water spray systems and fire detection devices. Efforts were made by Washington Group to gain more consistency in these items between sites.

After review, the design of the ECRs was considered sufficiently robust such that additional similar fires should have no significant impact. A detonation during shearing should not occur but if it does the building will withstand the explosive effects. Closure of the ECR doors on rockets was not addressed as a means of rocket initiation during the Army review, but had been noted in the hazard reviews. The SMEs felt that the closure of the outer door on a rocket should be considered and evaluated in light of any new information and the preventive maintenance program revised as necessary for the outer doors leading from the unpack area to the ECR with respect to the inadvertent closing of a door on a rocket.

The extensive analytical work at Picatinny was designed to help identify the root causes of rocket fires but, in the opinion of the SMEs gaps remain concerning the knowledge acquired versus items that need to be addressed in future rocket testing of Blue Grass rockets. The analytical work that was carried out by Picatinny did add significantly to the knowledge regarding the possible cause(s) of the rocket fires. There are questions as to whether NG exudate on the surface of the propellant grain is the cause of the fires. Some additional testing was conducted with the Pine Bluff rockets, particularly impact sensitivity testing of the propellant/inhibitor interface. Unfortunately, this testing was not conducted on the Umatilla samples. It is hypothesized by the SMEs that the loss of NG from the grain / inhibitor interface and the grain ends results in regions of "recrystallized" NC which are much more sensitive to impact as shown by the Pine Bluff test results. The increased sensitivity of this region may or may not be time dependent; therefore, more characterization is needed. Also, samples of the propellant grain have been tested at the cut locations only. No inhibitor layer exists at the grain ends and migration of NG might be more prevalent at these locations (potentially leading to NG-rich exudates and/or "recrystallization" near the grain ends). This is of concern as the present plan for the rocket separation will result in a cut near one of the grain ends.

In addition there were two more violent rocket fires at Umatilla that occurred upon initial impact of the blade on the rocket casing which have not been adequately explained. If exudate is the cause, then the rocket radial orientation may be of importance when the shearing occurs. It is recommended that Blue Grass rockets that are chosen for sampling be marked at the top and the



grain samples be obtained within 6 inches of the grain ends in addition to other locations identified previously. The tops of all rockets in storage should also be marked and oriented similarly during the cutting operation. The ECR rooms have been sufficiently designed to accommodate these events. However, because in the opinion of at least some of the SMEs the specific causes of these incidents have not been completely defined and there is at least some uncertainty as to whether additional risks extend beyond the processing area, especially in long term storage and handling.

There are also concerns over the exclusion to date of friction ignition testing of M62 pellets and powder. If this material is present in the trilobe area or fore-end spring cavity it could present an important source of fire initiation and will need to be considered for the Blue Grass design as current plans call for a cut to occur in this area.

Consequently, it is recommended that testing of rockets stored at Blue Grass be undertaken as soon as can be practically arranged and that some alternative hypotheses be further explored. Finally, testing of rockets stored at Blue Grass should take into account the rocket separation process being currently evaluated for the design of that site's chemical agent disposal facility. This facility will not be an incineration facility, but will be an alternate technology utilizing chemical destruction processes.

QRA Review

As mentioned earlier in the report, the original QRA conducted by SAIC was reviewed and appears thorough and complete based on information available at that time. However, it must be pointed out that leaking rockets were identified much later than that QRA and were therefore not included. The calculated risk levels from that original study are very low for both workers and the public.

An SME review of the risk analyses associated with the recent rocket fires updated by Mitretek was also completed. The recent fire events have been aggregated by Mitretek with historical data to provide a new estimated fire frequency based on "sensitive" rockets. This averaging process, which is based on a random probability model, appears to underestimate the true frequency. The corresponding increase in risk from this model is relatively small. However, if a time dependent degradation/ sensitivity process is occurring then this model is not correct and the risk levels would be higher. A statistical test should be employed to establish that the recent rash of events is within the statistical bounds of the earlier fire events (e.g. pre 2004) or not.

Blue Grass Storage Concerns

Testing should commence on the Blue Grass rockets as soon as practicable. Each subsequent round of testing has added new information and the testing of the Blue Grass should continue to further the knowledge regarding long term storage. A small sample of leaking GB rockets and some VX rockets should be included in the testing. Care must be taken to develop a plan to ensure the sampling can be conducted in a safe manner.

Testing of Blue Grass rockets should include:



Grain ends and grain inhibitor interfaces should be tested for:

- (1) Impact sensitivity. There is evidence in the Pine Bluff analyses that the impact sensitivity is much higher nearer the grain/ inhibitor interface. This may be due to the loss of NG gellation agent and the "recrystallization" of residual NC.
- (2) Measurement of any longitudinal migration of NG and any possible pooling of NG at the grain ends. How the rockets are stored could create higher concentrations of NG at either or both ends of the grain
- (3) Quantitative measurement of NC and quantitative breakdown of the forms of NC present near the inhibitor interface and grain ends. NC has traditionally been calculated rather than measured. If NC is playing a more significant role in the degradation/sensitivity processes this should help characterize that role.
- (4) Friction sensitivity tests of M62 pellets and powder. In addition to a scenario relating to the fire initiation process during cutting there is a concern that loss of pellets from their holder (this has been observed in a number of Pine Bluff samples) could result in contact and reaction with the grain in the trilobe area and possibly affect the rate of autog ignition.

CONCLUSIONS

- 1) While there seem to be some unknowns surrounding the destruction of rockets (e.g. leaking or sensitive rockets) there are no indications of immediate concerns for worker and public health that would preclude the continued processing of rockets. The destruction of rockets should be expedited in as safe a manner as reasonably practicable which will continue to reduce the potential risks. Leaking rockets should be moved up to the top of the list for processing.
- 2) The ECRs have a sufficiently robust design to minimize risk to workers and the public if further incidents occur during normal processing, other than a slightly higher risk to workers based on an increasing number of entries to the normally unmanned process area.
- 3) The modifications made by the systems contractor appear sufficient to potentially minimize the frequency of fires and contain/suppress the fires in the ECR; thereby minimizing public health risks and allowing a quick return to processing.
- 4) The actual root causes of the fires have never been completely substantiated. The recent report by Mitretek suggests the contact from the blade against NG exudates on the propellant grain as the most probable source of the fires originating during the shearing process. However, the migration of NG to the surface of the grain is a process that should reach equilibrium in a few years and therefore all the rockets in the stockpiles would have reached that steady state. Conversely, the lowest concentration of NG in the grain (at the grain / inhibitor interface), according to Pine Bluff analyses, corresponds to the greatest impact sensitivity which may not be due to a steady state phenomena. The recent fire events suggest that the fires may be occurring in a time dependent manner. In addition there is no inhibitor present at the grain ends to prevent migration of NG to establish equilibrium and the ends of the rockets have never been tested. Therefore, more extensive root cause analysis is necessary. At present there have been no incidents originating outside of the ECR.



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But until the root cause(s) can be specifically determined and any effects from some as yet unknown chemical degradation and sensitization processes are understood, there will remain some concerns over the longer term storage, handling and processing of rockets.

- 5) An additional cause hypothesized at the outset of the review by the SMEs is the possible initiation of a fire event via a thermite reaction. The steel blade will pick up bits of aluminum following cut #4 which could result in a reaction with rust on the inside surface of the rocket casing or just result in blunting of the blade. The water spray improvements might help in removal of aluminum debris but will more likely help in the quenching of any thermite reaction that might be initiated.
- 6) Testing and analysis of rocket samples has not been sufficient to completely identify the specific root cause(s) of the fire events. The recent testing by Picatinny for propellant stability has been somewhat limited to the extent described above in (4). In addition testing has not been completed on rockets stored at Blue Grass, either non-leaking or leaking GB rockets. It is especially important to identify possible degradation and sensitization processes at work with respect to the Blue Grass rockets as they are still years away from being processed.
- 7) The storage and handling of rockets has not been completely addressed from the standpoint of worker and public safety. This conclusion is stated because possible degradation processes within the rockets which could result in increased sensitization have not been adequately eliminated as concerns.
- 8) Updates of the risk analyses concluded the risk was time independent. However, this has yet to be fully confirmed.
- 9) No efforts have been made to evaluate the possibility of a rocket being inadvertently armed either due to:
 - a. General handling
 - b. Leaking of agent into the fuze assembly which potentially corrodes the metal springs
 - c. Prior improper assembly

There have been 2 incidents out of the 21 fire events related to fuze initiation which were not formally investigated and which have no attributable root cause. The fact that both of these occurred in 2005 with no prior incidents reported (An incident at JCADS was attributed to processing error) raised the concern of the SMEs. To the SMEs knowledge no significant investigation took place and no causes were identified. In addition, this item was not addressed in the Army report.

- 10) Leaking rockets in overpacks represent a potentially higher risk to workers and the public because of the occurrence of possible additional reactions, possible sensitization due to orientation of the rocket in the overpack, storage conditions and capability for heat removal, and the extended length of time before processing.
- 11) The recommendations developed by WDC were implemented differently at different sites due to site-specific permitting requirements.



RECOMMENDATIONS

- 1) Processing of rockets should continue as rapidly as can be accomplished safely. Leaking rockets should be moved to the top of the list.
- 2) A classic root cause analysis should be conducted to establish the cause(s) of fires taking into account hypotheses developed by the SMEs including storage and handling scenarios.
- 3) Additional testing of rockets should be undertaken to help establish further the root cause(s) for the fire events and to aid understanding of any possible degradation processes:
 - (a) Testing of Blue Grass GB rockets.
 - (b) Testing of GB leakers as soon as possible, particularly at Blue Grass. Evaluation of these leakers to determine if the results are consistent with current heat balance and autoignition models.
 - (c) Limited testing of VX rockets to help establish a baseline.
 - (d) Testing which will incorporate new cut locations based on the Blue Grass separation process design currently being considered.
- 4) Specific testing of the Blue Grass rockets should include:
 - (a) Sampling of grain ends, cut #5 and grain / inhibitor interfaces at those locations for;
 - (i) Impact sensitivity
 - (ii) Measurement of any radial and longitudinal migration of NG, including visible observations of the surface and any possible pooling at the ends.
 - (iii) Quantitative measurement of NC and analysis of the forms of NC present particularly near the inhibitor interface and at the grain ends.
 - (b) Friction sensitivity tests on M62 pellets and powder.
- 5) Standard Operation Procedures associated with storage, handling, and transport of rockets should be revalidated and periodic refresher training in those procedures conducted. The revalidation should consider any new information including increased sensitivity or a potentially armed fuze. In addition, recommendations from any previous studies should be included in the revalidation to ensure recommendations were completed.
Root cause(s) for the fuze events should be completed.
- 6) Igloo design and operation should be revisited to ensure previously identified mitigations were implemented or appropriate with respect to:
 - a) Recommended stacking heights (earthquake risk primarily)
 - b) Standoff distances from igloo walls to the pallets or other protection options for lightning strikes.
- 7) Temperature and humidity monitoring of the igloos still containing rockets should be improved.
- 8) The expected frequency of fires in the ECR should be recalculated. It does not appear reasonable to state that the recent rash of fires are not statistically different than the historical average prior to 2004. A statistical test should be employed to substantiate whether the overall average value is applicable or whether another model is more



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correct. If the latter, then the risk calculations for the workers and public should also be updated.

- 9) Potentially safer means of transport for rockets from the igloos to the unpack area should be considered based on possible increased impact sensitivity. The movement, transportation and handling of the rockets should be re-validated and reviewed to ensure the safeguards and procedures are being maintained and also updated based on any new data or information.
- 10) The casing on the upper side of all rockets brought to the unpack area (leakers and non-leakers) should be marked to establish the orientation of rockets as they existed in storage.
- 11) The SMEs felt that the inadvertent closure of the ECR outer door onto a rocket being conveyed from the unpack area should be considered and evaluated in light of any new information, and the preventive maintenance program revised as necessary.



Short Professional Bios of Members of the CDC M55 Working Group

Reviewer 1 (PhD in Fuel and Combustion Science, University of Leeds, England, Post-Doctoral Research Fellow in the Department of Electrical Engineering at the University of Southampton under contract to the Royal Navy) is an independent consultant specializing in loss prevention and accident investigation in the areas of flammability and reactive chemicals.

He is a fellow of the Energy Institute, the AIChE and a member of the Institute of Physics. He is both a Chartered Engineer and Chartered Physicist in the UK. He has published over 50 technical papers and contributed chapters to several books, including Perry's Chemical Engineer's Handbook (7th and 8th editions). .

He was employed by Union Carbide and subsequently by Dow Chemical and his responsibilities included the design and supervision of safety research programs.

He has served on more than a dozen national committees including NFPA, AIChE-CCPS, NTSC, ACC, and ASTM and is still active on several NFPA committees plus ASTM's E-27 committee for Reactive Chemicals.



M55 Rocket Fire/ Explosion Concerns

Reviewer 2 (PhD Yale University in Physical Chemistry) was formerly a Vice President and is now a consultant for Burgoyne Incorporated in Atlanta, GA. His particular specialties include accident investigations and expert witness assignments in fires and explosions, especially where electrostatic phenomena are of concern.

He is a registered Professional Engineer in the State of California in Safety Engineering and a Certified Safety Professional. He is a member of AIChE and the EOS/ESD Association. He has contributed a chapter to the *Fire Protection Handbook*, in addition to publishing numerous technical papers and books on the subject of electrostatic hazards. He also serves on the NFPA Committee for Static Electricity

He was formerly employed by Rohm and Haas at the Redstone Research Laboratory in Huntsville, AL where he established protocols for friction, impact, electrostatic and thermal testing for propellants and propellant ingredients. He then joined Hercules Corporation in their Hazard Evaluation and Risk Control Services (HERC) group at Rocket Center, WV. He has investigated numerous industrial accidents where gases, vapors, dusts and condensed phase materials were involved in deflagrations, detonations, thermal runaways and physical explosions.



M55 Rocket Fire/ Explosion Concerns

Reviewer 3 (PhD in Chemical Engineering, University of Oklahoma) is a Professor in the Chemical Engineering Department of Texas A&M University and Director of the Mary K. O'Connor Process Safety Center at the Texas Engineering Experiment Station.

He is a Registered Professional Engineer in the states of Louisiana and Texas and is a Certified Safety Professional. He is a co-author of the book, *Guidelines for Safe Process Operations and Maintenance*, published by the AIChE-CCPS and is currently the editor of the 3rd edition of a 3-volume reference on process safety, in addition to having authored over 120 publications in journals and proceedings.

Before joining Texas A&M he was a Vice President of RMT, Inc. a nationwide engineering services company. His experience is wide ranging including process design of chemical plants and refineries, mathematical modeling, process safety, hazard analysis and quantitative risk assessment, inherently safer design, and reactive and energetic materials assessments. His research interests include, among others, the application of calorimetric methods for the assessment of reactive hazards and computational fluid dynamics to study the explosive characteristics of flammable gases.



M55 Rocket Fire/ Explosion Concerns

Reviewer 4 (BS in Chemical Engineering, University of Rhode Island). He is currently self employed as a consultant. He served in the US Army at Edgewood Arsenal, in Edgewood MD.

He then continued his career with the Government as a civilian employee at the Chemical Research Laboratory at Edgewood Arsenal. After assignments of increasing responsibility involving the destruction of chemical weapons he was named Program Manager for Chemical Demilitarization and was a major force behind the design, construction and operation of the current family of demilitarization plants. In addition he personally directed the effort to produce the publication "US Army's Alternative Demilitarization Technology Report for Congress", which outlines the Army's proposals for future demilitarization efforts.

He is extremely knowledgeable in all aspects of the development and current status of the Chemical Demilitarization Program and in the design and operation of all the demilitarization plants.

Centers for Disease Control
and Prevention (CDC)
Atlanta GA 30333

May 5, 2006

Greg St. Pierre
Director, CMA Risk Assessment
US Army Chemical Materials Agency
5183 Blackhawk Road
Aberdeen Proving Ground, MD 21010-5424

Dear Mr. Pierre,

This letter is in response to questions posed to Terry Tinch, of the Center for Disease Control and Prevention's Chemical Weapons Elimination Branch, during a phone conversation on May 4, 2006. The questions involved clarification of the recommendations contained in the report of May 1, 2006 entitled *M55 Rocket Fire/Explosion Concerns*, detailing the results of CDC's review of the Army's investigation into M55 Rocket fires utilizing subject matter experts (SME) to provide individual recommendations and observations in regards to the investigation based on each member's expertise. CDC developed this report from those individual recommendations and observations and it contains conclusions and recommendations concerning the rocket fire investigation and especially the new process design being developed for the destruction of the Blue Grass, Kentucky stockpile of chemical weapons.

However, the recommendations were listed and did not distinguish between those that were majority recommendations and those that were minority. CDC has broken these into two categories, major and other recommendations. The major recommendations were those that were a majority consensus or key safety items. The other recommendations were those that were suggested by 1 or 2 of the SMEs and were included to ensure all their comments were captured.

The major recommendations were in three main areas, processing, root cause/ hazard analysis and testing. The processing recommendation involved the existing incineration facilities and the root cause/ hazard analysis and testing were considered major issues that need to be considered in the design of the Blue Grass facility currently being developed. These conclusions and recommendations are listed for clarity.

1. Conclusions and Recommendations Processing

- a. Processing of rockets should continue as rapidly as can be accomplished safely.

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Conclusions and Recommendations Root Cause/ Hazard Analysis

- b. A classic root cause analysis should be conducted to establish the cause(s) of fires.
- c. Root cause(s) for potential fuze events should be completed.
- d. The expected frequency of fires in the ECR should be recalculated.

2. Conclusions and Recommendations Testing

- a. Additional testing of rockets should be undertaken to help establish further the root cause(s) for the fire events and to aid understanding of any possible degradation processes, especially for the design of the Blue Grass Chemical Agent Pilot Plant. (please note in the report under Blue Grass Storage Concerns, it states that a small sample of leaking GB rockets and some VX rockets should be included in the testing. Care must be taken to develop a plan to ensure this sampling can be conducted in a safe manner. While CDC believes the data is important, the safety aspects of dealing with a leaking rocket must take priority)

The remaining conclusions and recommendations were primarily from individual SMEs and are broken down into storage and transportation, leakers and the Explosion Containment Room.

The issues with storage and transportation focused on recommendations found in previous hazards analysis and quantitative risk assessments. The intent is for the Army to ensure the original recommendations were implemented and are revalidated to ensure they are current and that new information is being incorporated. These conclusions and recommendations follow.

1. Conclusions and Recommendations Storage

- a. Igloo design and operation should be revisited to ensure previously identified mitigations were implemented or appropriate with respect to earthquakes and lightning strikes.
- b. Temperature and humidity monitoring of the igloos still containing rockets should be improved.

2. Conclusions and Recommendations Storage and Transportation

- a. Standard Operation Procedures associated with storage, handling, and transport of rockets should be revalidated and periodic refresher training in those procedures conducted

3. Conclusions and Recommendations Transportation

- a. The movement, transportation and handling of the rockets should be revalidated and reviewed to ensure the safeguards and procedures are being maintained and also updated based on any new data or information.

There was concern with leaking rockets and the consequences. There was not consensus among the SMEs on some of these issues; however, CDC believes it is important the

Army understands there are concerns and addresses them. These recommendations and conclusions involve the following.

1. Conclusions and Recommendations Leakers

- a. Leaking rockets should be moved to the top of the processing priority.
- b. The casing on the upper side of all rockets brought to the unpack area (leakers and non-leakers) should be marked to establish the orientation of rockets as they existed in storage.

Finally, there was some concern about safeguards for ensuring an incident with a rocket would not occur outside the Explosion Containment Room (ECR). CDC would like for the Army to verify this issue was reviewed in the hazards analysis, what safeguards are in place and ensure it is part of the preventative maintenance program. Specifically, the conclusion and recommendation is stated as follows.

1. Conclusions and Recommendations ECR

- a. The SMEs felt that the inadvertent closure of the ECR outer door onto a rocket being conveyed from the unpack area should be considered and evaluated and the preventive maintenance program revised as necessary.

We hope this clarifies the conclusions and recommendations of the report on *M55 Rocket Fire/ Explosion Concerns* and enables you to effectively prioritize and address these concerns. CDC thanks you for the assistance in providing data and information for this report and appreciates your interest and concerns. Please contact Mr. Terry Tincher at (770) 488-4153 if you have any questions regarding this report.

Sincerely,



Paul Joe, DO, MPH
Acting Branch Chief
Chemical Weapons Elimination Branch (F-16)
Division of Emergency and Environmental Health Services
National Center of Environmental Health